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INITIAL Reactor Safeguards Laboratory

MNRC Safeguards, Core Cooling, and Calorimetric laboratory - 3.0 hours.

Overview

The safeguards and core cooling laboratory will consist of sample activation, sample measurement and sample analysis. Two activation samples of natural UO_2 will be irradiated in the reflector region of the McClellan Nuclear Research Center (MNCR). One sample will be cadmium covered and the other will **not** have cadmium covering (bare). Both samples will be measured[i] with a HPGe detector, where energy and efficiency calibrations are necessary. Analysis is detailed below in the analysis section.

Introduction

The birth of nuclear technology also brought about the birth of nuclear non-proliferation. Nuclear non-proliferation is the discipline dedicated to stopping the spread of nuclear weapons. Weapons States[ii] (WS) having signed the **Treaty on the Non-Proliferation of nuclear weapons (NPT)** have agreed to provide nuclear technology to Non-Weapons States[iii] (NWS) and to "move forward" in nuclear disarmament. NWS conversely have agreed to receive nuclear technology in exchange for not pursing weapons of mass destruction.

Nuclear safeguards are measures to verify that civil nuclear materials are properly accounted for and not diverted to undeclared uses and that nuclear facilities and technology are not misused for the purpose of producing a nuclear explosive device. Both WS and NWS are subject to safeguards. In the US, the NRC performs safeguards responsibilities[iv], while the International Atomic Energy Agency (IAEA) applies safeguards for NWS.

In either case, the "fundamental safeguards measure"[2] is **Nuclear Material Accountancy (NMA)**, referring to "activities carried out to establish the quantities of nuclear material present within defined areas and the changes in those quantities within defined periods"[3, Section 6.2]. NMA responsibilities exist at the facility, State, and IAEA levels. At the facility level, nuclear material is to be split into **Material Balance Areas (MBAs)** and material is to be tracked with reference to these MBAs. The State then provides this information to the IAEA, and the IAEA independently verifies the nuclear material accounting information provided.

Different facilities have different types of accounting. **Item accounting** is used for fuel rods, fuel assemblies, etc, while **bulk accounting** is used for powders and solutions. In a reactor facility (like the MNCR), item accounting it typically utilized. In this case, the goal of the IAEA is to **verify** item number as well as composition. Composition is important because individual items may be "modified" so that fissile material is diverted for nefarious purposes. To verify individual items as well as composition, the IAEA would *ideally* like to determine: assembly serial number, fuel burnup, plutonium inventory of fuel, and fuel assembly integrity.

Determining this information without compromising the item like nature of the assembly limits the types of measurements that can be taken. Measurements are limited to: neutron

[i] We will **not** be measuring the samples we irradiate during the laboratory, but rather samples that were irradiated in a like manner, and allowed to radioactively decay for at least a month.

[ii] States having detonated a nuclear device before Jan 1. 1967: US, Russia, UK, France, and China[1, Article IX – Par. 3]

[iii] The other signatories to the NPT (186 States)

[iv] https://www.nrc.gov/about-nrc/ip/intl-safeguards.html

emissions, gamma-rays, Cerenkov Radiation, and calorimetric measurements (very optimistically). How some of these measurements are tied to valuable information will be discussed during the analysis portion of the laboratory.

In this laboratory, we will irradiate small quantities natural uranium, which will emulate spent fuel, and further we will *verify* the time since removal from reactor and burnup of the UO_2. The heat emission rate will also be determined. This will be done through gamma measurements, a large number of assumptions and favorable irradiation conditions.

Purpose

Have students comprehend and familiarize them with:

- Safeguards role in nuclear power plant operations.
- That fission product composition of irradiated fuel changes as a function of time.
- The difference between thermal and fast fissions (with corresponding applications of each).
- How spent fuel decay heat calculations can be conducted and why commercial spent fuel needs to be water cooled for several years.

Activation Constraints/Conditions

Material – The material to be irradiated is natural uranium dioxide (Purchase).
  - Chemical Form - UO_2
  - Density - 10.97 g/cc
  - Enrichment 0.72 at.% ^{235}U
  - Mass - 10 grams

Irradiation Time – Will be determined in two ways for the two different experiments:
  1. Bare experiment: Dictated by the length of time it takes for the system to produce 0.5 μCi of ^{137}Cs (See Equation **??**).
  2. Cd experiment: $T_{irr,Bare} < T_{irr,Cd} < 24$ hrs. The dose rate will be less than or equal to the dose rate of the bare experiment at measurement time.

Neutron Scalar Flux – The thermal (<0.5 eV) scalar flux (ϕ_{therm}) is 3×10^{11} n/(cm$^2\cdot$s).

Materials (most will be provided)

- Laboratory Notebook with these instructions (will not be provided)
- $UO_2 \sim 50$ grams
- Al foil
- Lead Shielding
- Nuclear reactor
- Gamma calibration standard (for both energy and efficiency)
- HPGe detector

Experiment

UO_2 Preparation

Refer to professors instructions.

UO_2 Irradiation

Refer to professors instructions.

UO_2 Measurement

Depending on the software used for gamma data collection as well as available calibration sources, this section will be variable, but in essence for both bare and Cd experiments:

- Measure many peak source (^{152}Eu?)
- Calibrate gamma detector (if GENIE/FRAM/Peak Easy software used can provide instructions)
- Determine spot where sample will be placed
  - 1 meter distance (depends on irradiation time, cooling) – don't really want students to play around with the source, we can figure the proper distance beforehand, so that dead-time is appropriate.
- Have instructor place source
- Students start data acquisition

Requested Analysis

You, as an IAEA inspector, know that verification of fuel burnup, as well as time since removal from reactor is important so that valuable special nuclear material is accounted for. The task set before you, for two fuel items, is to do just that. The reactor operator (your professor), has declared to you both the burnup and time since removal from reactor for these two items. With your gamma spectroscopy measurements, please verify your professors statements by providing the following values.

1. The time you estimate that the fuel was removed from the reactor (for both experiments)
   - Be sure to list relative activities used for this calculation
2. The burnup you estimate for the fuel (for both experiments)
   - Be sure to list either isotope ratios used for this calculation or the absolute ^{137}Cs activity used for this calculation
   - Your professor should provide the initial mass of heavy metal if the ^{137}Cs route is chosen

In addition, please answer the following:

1. If the burnup were determined with the activity of ^{137}Cs alone, what other major burnup contributor would need to be considered?

2. Why does this contributor not play a large role a thermal reactor? (might be a difficult question)

3. If this contributor were to play a large role, how could your estimates differ from the reactor operators declaration?

With this information, you are able to verify whether or not the operators declarations are correct. Your last analysis task is of calorimetric concern. Please provide the following:

1. The heat coming off the fuel from the isotopes undergoing beta decay.

2. The heat coming off the fuel from isotopes undergoing alpha decay (hint: ^{238}U, and ^{235}U, are the only isotopes to be concerned with – ^{239}Pu exists in very small quantities in the system, also assume that the concentrations of ^{238}U and ^{235}U don't change during the course of irradiation).

In addition, please answer the following:

1. Of all the heating sources in the sample (alpha, beta, gamma, neutron), which contributes the most towards heating in **our** samples?

2. Why would this fuel not need to be cooled for an extended period of time, while reactor fuel, with their higher burnups, need to be cooled for much longer?

Finally, due to the fact that the facility you are visiting is a reactor type facility, where material accountancy is used for tracking special nuclear material. Please provide the following.

1. A sketch of Material Balance Areas (MBAs) that you think would be necessary for this facility for the special nuclear material. Recall from your training that an MBA is an area inside or outside a facility such that:
   - the quantity of nuclear material in each transfer into or out of each MBA can be determined
   - the physical inventory of nuclear material in each MBA can be determined when necessary

2. On your sketch of MBAs (you could potentially only have one MBA – just provide a reasoning for each MBA), please note down Key Measurement Points (KMP) in the facility. Reacall from your training that a KMP is:
   - a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory
   - KMPs include the inputs and outputs and storages in MBAs (don't forget material has to arrive at the facility at some point

References

[1] International Atomic Energy Agency. *INFCIRC/140 (Treaty on the Non-Proliferation of Nuclear Weapons)*. International Atomic Energy Agency, Vienna, 1970.

[2] International Atomic Energy Agency. *Nuclear Material Accounting Handbook*. Number 15 in IAEA Services Series. International Atomic Energy Agency, Vienna, 2008.

[3] International Atomic Energy Agency. *IAEA Safeguards Glossary*. Number 3 in International Nuclear Verification Series. International Atomic Energy Agency, Vienna, 2002.